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ARE THE EU'S POLICIES CONTRIBUTING TO INCREASED DEPLOYMENT OF RENEWABLE ENERGY SOURCES? AN EMPIRICAL ANALYSIS

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Abstract: The European Union has placed great importance on energy policy, namely on renewable energy, as it plans to phase out fossil fuel sources in the coming decades. However, the presence of renewable energy has been a constant since the beginning of the millennium. This thesis aims to assess whether the renewable energy policies introduced in the EU since 2000 were effective in increasing the deployment of these energy sources. We find evidence that feed-in policies (tariffs and premiums) and quotas had a significant effect on renewable energy deployment, while tenders and tax incentives did not have a significant effect.

Keywords: Renewable energy, policy instruments, European Union

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1 Introduction

"I want Europe to become the first climate-neutral continent in the world by 2050." This sentence was part of a speech delivered by the recently appointed European Commission President, Ursula von der Leyen, in her opening statement in the European Parliament. It was merely a confirmation of what was an already known priority for the European Union and its members, the environment and climate change. And, as social pressure and public demonstrations increased, highlighted by the meteoric rise in popularity of activists such as the Swedish teenager, Greta Thunberg, a formal declaration of intentions was needed. However, the EU's concern for the sustainability of the planet was not triggered by this recent uproar. Instead, it has been present in its institutional decisions for over 20 years.

In 2001, the EU recognised the necessity to promote alternative, less pollutant, renewable energy sources for the production of electricity. The European Parliament and Council issued Directive 2001/77/EC (Communities, 2001), known as the RES directive, which established national and community targets, clarifying the steps to be taken to increase the deployment of renewable energy. More recently, this directive was replaced by Directive 2009/28/EC (Union, 2009), which updated the renewable energy targets, setting an ambitious goal of 20% of EU energy having its origin in renewable energy by requiring each member state to create a national plan to achieve the established targets. Directive 2009/28/EC (Union, 2009) was the document that guided this past decade's renewable energy policy.

Both documents, however, acknowledged that investment in renewable energy was unlikely to appear organically, due to its low competitiveness, and needed to be publicly supported.[1] As such, it was determined that support schemes should be designed and implemented, as to increase renewable energy deployment and to facilitate the penetration of these energy sources.

As the 2010 decade comes to an end and the year of 2020 approaches, the targets are on track to be met, and in some cases surpassed. The EU and its members were largely successful in increasing the share of renewable energies. Support schemes implemented in the beginning of the 21st century are now being modified and its benefits reduced, as RE becomes more competitive. However, in times where a cycle is ending, a question remains, were the support schemes effective in deploying renewable energy in the European Union?

In this thesis, we investigate to what extent the instruments used to support RE were responsible for the increased share of these sources in electricity production. We analyse a panel of all 27 members of the EU and the United Kingdom, from 2000 to 2017. We divide the instruments into four categories, according to their characteristics and their focus, and estimate to what degree they have affected changes in capacity from renewable energy, a proxy for investment in RE. We analyse the total investment in RE and in three types of energy separately, that is, solar, wind and biomass. Our results indicate that some support schemes were, in fact, effective in promoting renewable energy. Particularly, feed-in policies, such as tariffs or premiums, and quota obligations were found to have a significant effect on the deployment of those energy sources. We contribute to the literature by analysing the effectiveness of four different instruments across the 27 members of the EU and the United Kingdom on deployment of total RE

[1] Negative externalities of fossil fuels were not internalised due to a sluggish ETS market.

capacity and capacity from three different sources. To the best of our knowledge this is the first analysis to do so, as other articles have generally focused on analysing at most two policy instruments or on analysing a single energy source.

This article is structured as follows. Section 2 discusses and reviews the literature on renewable energy policy effectiveness. Section 3 presents and discusses the policy instruments in the EU, while Section 4 describes the data used in the analysis. Section 5 presents the empirical approach. Section 6 describes the results and discusses its implications. Finally, Section 7 concludes the thesis. Tables are included in the appendix.

2 Literature Review

Policies promoting use and deployment of renewable energy sources are relatively recent. Although the first explicit support policy in Europe was enacted in 1979, in Denmark, the majority of European countries only followed the Danish example in the 1990s or in the 2000s (Kitzing et al., 2012). Yet, the literature assessing and evaluating the effect of the policies in the deployment of renewable energy is extensive. Earlier articles relied on a qualitative approach, analysing countries individually or comparing them. More recently, and as these policies become effective, research has become more quantitative.

Qualitative articles focused primarily on analysing individual case-studies or the trend of renewable energy deployment. Bird et al. (2005) was one the earlier articles examining the effects of policy on the expansion of RE. The authors found that Renewable Portfolio Standards (RPS) and tax incentives were relevant for the deployment of wind power energy in the US.[2] Alagappan et al. (2011) analysed 14 electricity markets across Europe and North America and concluded that a properly designed feed-in policy produced better results, when considering installed capacity. Notwithstanding the relevance of the US in these studies, much focus was devoted to European countries' policies, namely to the German case. Both Mitchell et al. (2006) and Butler and Neuhoff (2008) compare the German experience with feed-in policies, with the UK's alternative measures. The former found that German feed-in policies were more effective than the UK's quota scheme, as these

[2]Policy instruments are explained and discussed in Section 3.

failed to reduce risk for investors. The latter reached a similar conclusion, adding that feed-in policies delivered better prices and a more competitive environment than quotas. Lipp (2007) again compared Germany to the UK, but included Denmark, which had also implemented a feed-in policy scheme. The findings were similar, as evidence showed that the deployment of renewable energy was larger in both Denmark and Germany. Haas et al. (2011) produced a comprehensive analysis of the implementation of policies in the EU, which included case studies about four different types of schemes (feed-in policies, tenders, investment incentives and quotas) and concluded that feed-in policies were the most effective scheme for total RE production, as well as solar and wind.

One of the earlier quantitative studies was by Menz and Vachon (2006). Using a panel of 39 US states, the authors analyse how state and federal policies have contributed to wind power deployment. They find a positive effect of RPS and green power requirements, a scheme which requires suppliers to provide green power options to consumers. This study, however, was based in a short time period. Carley (2009) extended the analysis to all US states over nine years, finding contradicting results. While RPS had no significant effect on the share of RE generation, they did increase the total amount generated from RE. Shrimali and Kniefel (2011) find that policy has a relevant role on the share of RE capacity. Analysing 50 US states, from 1991 to 2007, the effect of green power requirements is positive for all types of RE in the analysis (wind, solar, geothermal and biomass), while RPS only have a positive effect on RE from solar and geothermal sources.

Also, in the US, Delmas and Montes-Sancho (2011) find different consequences for different policies. Using a two-step approach (logit and tobit) they conclude that RPS have a negative effect on RE capacity, while green power requirements have a positive effect. Yin and Powers (2010) create a variable to account for RPS heterogeneity in the US and find that it has a positive effect on the share of generation from RE, analysing all US states between 1993-2006. Hitaj (2013) consider wind power in a 10-year panel of US counties and find that policy had a significant role in the deployment of wind power capacity.

Analysing policies in Europe, Jenner et al. (2013) create a variable measuring return on investment to analyse the effect of feed-in polices in solar and wind capacity in 26 EU countries. They find that both sources' capacity benefits from a feed-in policy and highlight the importance of policy design, namely the duration of the policy and the amount of the monetary incentive. Hitaj et al. (2014) also find that feed-in policies contributed to an increase in wind capacity in German counties. Nicolini and Tavoni (2017) analyse a 11-year panel for the five largest EU countries across multiple renewable sources. They find that, although quotas with green certificates are effective, feed-in policies are better at stimulating both capacity and production in the short and long run. Kilinc-Ata (2016) combine 50 US states and 27 EU members and analyse them together. They use four binary variables, representing four different policies, and find that price-based incentives are better than quantity-based ones, when assessing the effect of policy on the share of electric capacity from RE sources. To date, we may conclude that most of the research finds that policy has played a positive role on the deployment of renewable energy.

3 Policy Instruments

Support schemes directed at renewable energy are often a combination of different types of policy. These policies can be of a regulatory or of a voluntary nature, direct or indirect, focused on generation or on investment and can be price or quantity-based. Table 1 describes which criteria each analysed policy instrument meet.

Table 1: Types of Policy Instruments

		Direct	
		Price-driven	Quantity-driven
Regulatory	Investment focused	Investment incentives Tax credits	Tendering system for investment grant
	Generation focused	Feed-in policies Fixed premium systems	Tendering system for long term contracts Quotas

Source: Adapted from Haas et al. (2011).

There are two relevant distinctions that need to be explicit with regards to policy instruments. The first is between a regulatory policy and a voluntary policy. As their names indicate, a voluntary policy is optional and, as such, its implementation is not mandatory, while a regulatory policy is binding and applicable from the time it is put into force. The present analysis will focus on regulatory policies.

The second important distinction is between direct and indirect policies. While the former aims at achieving an immediate effect on its desired target (renewable energy), the latter's objective is to promote a long-term effect and to improve the context for renewable energy deployment and development. This analysis will focus on direct policy instruments. Table 2 shows the evolution of the usage of the instruments in the EU.

Table 2: Number of countries with each policy 2000-2017

	2000	2005	2010	2015	2017
Feed-in tariff	9	19	22	24	24
Quota	2	6	6	6	5
Tender	3	4	1	2	3
Investment grant/ tax incentive	4	6	6	6	5

Source: Author's elaboration

3.1 Feed-in Policy

Feed-in policies have been the most popular instrument in the EU throughout the analysed period and encompass two similar, yet distinct, options: feed-in tariffs and feed-in premiums. These policies, which offer tariff-based incentives, provide a guarantee to producers that all their output will be absorbed by the grid and energy suppliers, reducing the risk for the investor, and increasing the attractiveness of RE projects.

The main components of a feed-in contract (duration and price) are pre-determined. The duration of the incentive is determined through one of two ways: either a set number of years (most commonly, between 15 and 25 years) or until a contracted amount of production is reached. The price to be received by producers covers both the cost of the RE project and an expected profit. Moreover, feed-in policies can differentiate between technologies (e.g wind or solar) and locations of projects to reflect the priorities and preferences of the regulatory entities.

Feed-in tariffs are the more advantageous instrument from the investor's perspective.

They guarantee revenue for the producer, regardless of whether there is demand for their production, which results in RE producers being exempt from market participation. The tariff is determined independently of the market and its price.

A feed-in premium scheme differs from a feed-in tariff, since producers interact with the market and sell their output there, receiving a premium above the market price. The premium can be fixed or sliding. In the first case, the premium is constant. Because this implies uncertainty regarding the total value producers receive, either the premium or total revenue can be bounded, by introducing minimum and maximum values. The latter implies a variable premium that changes with the evolution of market prices.

3.2 Investment Grant / Tax Incentive

Investment grants and tax incentives are policy instruments that aim at increasing investment in renewable energy sources. Although their objective is the same, the way in which they are granted differs.

Investment grants are a scheme in which non-repayable financial support is given to investors. It does not have a quantity based target, meaning that there are no predetermined levels of generation that need to be reached. Instead, grants are given by project. Financing entities are both national (governmental entities) and supra-national (EU institutions). The support is contracted in the early stages of the project and its payment can be delivered at multiple stages of the project, with part of the support being contingent on the performance of the facility. Typically, the grants cover between 5% to 70% of the total cost incurred.

Tax incentives contain both direct and indirect incentives. However, the latter do not have the characteristics to be considered a policy instrument in this study, as their effect is due to internalisation of the external cost. Direct tax incentives are implemented through a reduction of taxes, either through tax credits, deductions or exemptions. In the EU, direct support can be reflected in income tax, in VAT or in taxes levied on energy producers or consumers.

3.3 Quota

Quota obligations represent a mandatory level of energy from renewable sources that must be present in the energy portfolio of an entity. The quota of renewable energy is determined by a government entity, either at a local or national level, and can be expressed as a percentage of total energy (e.g. 20% of total energy must be produced using RES) or as a fixed amount of energy (e.g. 6 000 MWh must be produced using RES). Typically, these obligations fall on grid operators or energy suppliers. In fact, quotas are an instrument regulating the quantity of renewable energy produced.

To better access compliance with the quota, the method used is the issuance of certificates, called Tradable Green Certificates (TGC) or Renewable Portfolio Standards (RPS), where each certificate corresponds to a pre-determined amount of renewable energy. In general, each certificate represents a unit of energy produced using RES. Depending on the objective of the instrument, TGC schemes can be uniform or banded. In a uniform TGC scheme, the quota is technology neutral, since each unit of energy equals a certificate, regardless of which specific technology was used to produce it. Thus, this scheme is preferred when the purpose is to foster overall investment in RES. On the other hand, a banded (or differentiated) TGC scheme grants more (or less) certificates for the same unit of energy, depending on the technology used to produce it. A banded scheme is better suited when the objective is to prioritise investment in a specific technology.

TGC are tradable and selling them represents an additional source of revenue for producers. This is intended to incentivise investment in RES and in generation from them, by making investment profitable. The price of these certificates is determined by supply and demand in a dedicated market, although in some cases a minimum price can be set by the regulatory entity. Not meeting the quota carries penalties, which also affects the price, as the penalty (which is set administratively) is generally higher than the market price.

3.4 Tender

Tenders are competitive schemes which allocate support for the deployment of renewable energy projects. The tender process is conducted by public authorities or governmental entities, that call for bids to be made for a project or group of projects. The projects may consist of an amount of capacity to be installed, a level of production to be reached or, less often, the long-term price offered to producers or the growth of production over time.

Each tender has multiple assessment criteria, which are then used to select the winning bid. Often, the bid with the lowest level of support required is the chosen one. As with other instruments, a tender can either be technology neutral, not discriminating between different generation technologies, or technology specific, and favouring a particular one.

Tendering schemes are typically used together with other support schemes, often with feed-in tariffs or premiums and with investment grants, although they can also be used in conjunction with quota obligations with TGC.

4 Data

4.1 Data and Sample

We combined publicly available data to create a country-year panel data set, which spans from 2000 to 2017 and includes all 27 European Union countries and the United Kingdom. While not being long enough to cover periods where there were no renewable energy policy instruments enacted in all countries, the sample period does capture significant disparities in electricity capacity from renewable sources.

4.2 Dependent Variable

Reviewing the literature provided us with various possible options for a variable that represented the deployment of renewable energy and its influence in electricity production. Our choice is ***Added Capacity*** from renewable energy sources (Hitaj, 2013), as it is superior to outright capacity from renewable energy or any renewable electricity ratio

(Jenner et al., 2013). The latter was disregarded because the use of a ratio entails changes to the variable, which would fall outside of our interest, while support schemes' objectives lie in the promotion of renewable energy and not on its weight on total production. The former was ignored because, in order to successfully evaluate the effect of a policy, we must exclude previous investments in capacity, to disregard any possible trend.

The installed capacity does not include hydropower as one of its sources. This is due to concerns regarding the environmental impact of this source (Brunnschweiler, 2010), as well as the fact that most support schemes are not directed at hydropower projects. The renewable sources included are photovoltaic (solar), wind and biomass. The data were collected from the International Renewable Energy Agency (IRENA) database and is measured in gigawatt (GW).

4.3 Renewable Energy Policies

To assess the effect of regulatory action on renewable energy deployment we use a set of binary policy variables (Carley (2009) and Kilinc-Ata (2016)), representing whether a policy was enacted in a country, in which case it assumes a value of 1, or it was not enacted, assuming a value of 0. The variable remains with a value of 1 for as many years as the policy was effective. There are four binary variables, each corresponding to an instrument detailed in Section 3. For a policy to be considered enacted and effective, it need not be applicable to all renewable energy sources. For example, should a feed-in policy be available exclusively for photovoltaic energy, the policy variable for feed-in policies will take the value of 1.

One disadvantage of the setting described above is that it disregards within policy heterogeneity. Indeed, policies can vary in more instances than just type, such as the technology they target or the mechanism within each type. To mitigate this adversity, we also include energy specific policy variables. These variables are similar to those above, with the exception that for their value to be 1 the policy must be enacted for a single energy source.

The data for the construction of these variables were collected from multiple sources, which were then compared and combined, to assemble the most accurate database. The sources used were the IEA/IRENA Policy and Measures Database, CEER reports and Held et al. (2015).

4.4 Control Variables

We include several control variables that affect the decision to add productive capacity from renewable energies. The control variables can be divided into two groups: socio-economic variables and energy variables.

Socio-economic Variables: ***GDP per capita*** represents the natural logarithm of Gross Domestic Product per capita, in PPP dollars at constant prices. It objective is to control for income and wealth effects on RE deployment. These effects can be twofold. First, higher income could translate into more availability for the promotion of environmentally friendly energy options, such as RE sources. Second, higher income could imply a greater use of non-renewable energy sources, resulting from improved living standards more easily achieved by maintaining fossil fuel sources. The data were collected from the World Bank database.

Left represents the political leaning and environmental preference of a country's citizens. It value equals the percentage of votes given to left-wing parties. Traditionally, environmental causes have been associated with left-wing parties, which would point towards a higher representation of left-wing parties translating into more support for investment in RE capacity. Although seldom used as a variable, Fabrizio (2012) and Hitaj et al. (2014) obtained interesting results from it. The data were collected from the ParlGov database (Döring and Manow, 2018), and the built-in left-right index (0-10, with 0 representing far-left and 10 far-right) was used to sort the seats. A party was considered to be left-wing if the index was below 5.[3]

The binary variable ***EU Member*** identifies whether a country is a member of the European Union (1), or is not a member (0). The decision to include this variable lies in the fact that there were considerable changes in the number of member states of the EU

[3]In election years, the percentage is considered to be of that year only if the election occurred in the first semester.

during our sample period. As such, it should be controlled for whether being an effective member has an impact on capacity additions. The data were collected from the European Commission.

Population Density denotes the number of people per square kilometre. It is related to the potential for the creation of new production units, as land availability is an important factor for the deployment of new equipment to capture the power from renewable sources. Lower population density indicates greater land availability, which facilitates investment and construction of sites, such as wind farms or photovoltaic power plants. The data were collected from Eurostat.

Energy Variables: The ***Electricity Consumption*** variable quantifies the amount of electricity consumed in terawatt hour (TWh). The reason for its use relates to its characteristics as a proxy for market size and demand. The data were collected from Eurostat.

CO_2 emissions quantifies the emissions of carbon dioxide, in tonnes, per capita. We include it in the control variables since the the production of energy from non-renewable sources causes emission of harmful compounds which have a local impact. As such, this variable proxies those emissions. Higher levels of CO_2 (and by extension, pollutants from energy production) create less desirable living conditions and are thus associated with social pressure towards less polluting energy sources, such as RE sources.[4] The data were collected from the European Environment Agency database.

Share of Fossil Fuels controls for the amount of electricity produced from fossil fuels in TWh. Sovacool (2009) show that the transition towards RE sources is constrained by the strength of fossil sources and the socio-technological barriers they pose. This pressure could be either economic or political, through lobbying. As such, higher shares of fossil fuels should reduce the willingness to add RE capacity. The data for this variable were collected from Eurostat.

Table 7 in the appendix outlines the variables described above. Table 3 presents the summary statistics.

[4]Reduced levels of CO_2 emissions determine lower levels of local pollutants.

Table 3: Summary statistics

Variables		Observations	Mean	Standard Deviation	Min	Max
Added Capacity (Total)		476	.620	1.475	0	11.098
Added Capacity (Wind)		476	.329	.736	0	6.125
Added Capacity (Solar)		476	.230	.893	0	9.539
Added Capacity (Biomass)		476	.069	.156	0	1.045
Total	Feed-in Policy	476	.712	.453	0	1
	Quota	476	.195	.397	0	1
	Tender	476	.086	.281	0	1
	Tax incentive	476	.195	.397	0	1
Wind	Feed-in Policy	476	.611	.488	0	1
	Quota	476	.195	.397	0	1
	Tender	476	.082	.275	0	1
	Tax incentive	476	.166	.372	0	1
Solar	Feed-in Policy	476	.668	.471	0	1
	Quota	476	.180	.385	0	1
	Tender	476	.053	.223	0	1
	Tax incentive	476	.183	.389	0	1
Biomass	Feed-in Policy	476	.655	.476	0	1
	Quota	476	.195	.397	0	1
	Tender	476	.057	.232	0	1
	Tax incentive	476	.153	.361	0	1
GDP per capita		476	10.333	.404	9.143	11.491
Left		476	.435	.104	.163	.726
EU Member		476	.887	.317	0	1
Population Density		476	171.065	244.745	17	1495.299
Electricity Consumption		476	102.163	137.745	1.569	547.284
CO_2 Emission		476	8.605	3.971	3.243	28.760
Share of Fossil Fuels		476	90.663	133.842	.221	543.921

5 Empirical Approach

Analysing our dependent variable, ***Added Capacity***, and its distribution, we conclude that the most appropriate method is the Tobit model, first introduced in Tobin (1958). Since in some observations, there are no additions to capacity, the dependent variable is censored and has a value of zero with positive probability. The estimator for the random-effect Tobit model is obtained through maximum-likelihood.

Let latent renewable energy capacity additions, y^*_{it}, depend on the vector X_{it}, which contains both the policy variables and the control variables described in Section 4. Then,

$$y^*_{it} = X_{it}\beta + \epsilon_{it}, \text{where } \epsilon_{it} \sim N(0, \sigma^2) \tag{1}$$

and

$$\epsilon_{it} = \nu_i + \eta_{it} \tag{2}$$

for all countries i=1,..., N and all time periods t=1,..., T. The observed variable is

$$y_{it} = \begin{cases} y^*_{it}, & \text{if } y^*_{it} > 0. \\ 0, & \text{if } y^*_{it} \leq 0. \end{cases} \tag{3}$$

The error term ϵ_{it} consists of a time-invariant country-specific random effect ν_i and an idiosyncratic error η_{it} that varies over time and across countries. Moreover, we assume that $\forall\ i \neq j,\ t \neq s$:

$$E[\nu_i \nu_j] = 0, \nu_i \sim N(0, \sigma^2_\nu) \tag{4}$$

$$E[\eta_{it}\eta_{is}] = 0, \eta_{it} \sim N(0, \sigma^2_\eta) \tag{5}$$

and that the country-specific random effect ν_i is orthogonal to X_{it}. This assumption implies that any unobserved time-invariant country-specific variables that affect renewable energy deployment and that are not included in the estimation would be contained in the error term ν_i.

The zero covariance assumption means that the error term is uncorrelated across countries or over time.

We will apply this approach at two instances. First, we consider the added capacity from all RE sources. Second, we will divide the analysis into three distinct energy sources, wind, solar and biomass. This allows us to capture potential policy heterogeneity.

6 Results and discussion

6.1 Total renewable capacity

Table 4 reports the results of the Tobit estimation of capacity additions as a function of RE policies and controls. Column (1) presents the estimations when all policies are considered simultaneously, while columns (2) to (5) present the results when each policy is considered separately. All specifications use the same control variables.

Table 4: Tobit marginal effects - total RE

Dependent Variable	Capacity Additions (GW)				
	(1)	(2)	(3)	(4)	(5)
Feed-in Policy, (0/1)	0.592***	0.496***			
	(0.158)	(0.144)			
Quota, (0/1)	0.623**		0.444		
	(0.287)		(0.304)		
Tender, (0/1)	0.014			-0.146	
	(0.174)			(0.172)	
Tax incentive, (0/1)	0.080				-0.069
	(0.177)				(0.175)
GDP per capita, ln	-0.288	-0.285	-0.200	-0.203	-0.209
	(0.355)	(0.344)	(0.370)	(0.359)	(0.359)
Left, %	0.656	0.585	0.804	0.746	0.721
	(0.614)	(0.611)	(0.620)	(0.619)	(0.621)
EU Member, (0/1)	0.136	0.190	0.380**	0.403**	0.390**
	(0.203)	(0.200)	(0.193)	(0.192)	(0.193)
Electricity Consumption, TWh	0.032***	0.032***	0.034***	0.034***	0.034***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Population Density, population/km^2	0.000	0.000	0.000	0.000	0.000
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
CO_2 emissions, tonnes per capita	0.030	0.023	0.007	0.006	0.006
	(0.029)	(0.029)	(0.030)	(0.030)	(0.030)
Share of Fossil Fuels, (TWh)	-0.026***	-0.025***	-0.028***	-0.027***	-0.027***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Constant	1.308	1.489	0.772	0.890	0.976
	(3.455)	(3.341)	(3.619)	(3.494)	(3.490)
Countries	28	28	28	28	28
Observations	476	476	476	476	476
Censored Observations	53	53	53	53	53

Standard errors in parentheses. *, **, and *** denote significance at 10%, 5%, and at 1% respectively.

Although not the main subject of this study, we will briefly explore the control variables' results, as their coefficients point towards noteworthy findings. The first result is that the direction of the coefficients does not change across specifications and there are only marginal changes in their significance. GDP per capita is shown to have a negative, albeit not significant, effect in deployment of RE capacity. Theoretically, one would expect wealthier countries to possess better conditions for the deployment of RE, not only in investment capability, but also in willingness to pay higher commodity prices. However, considering that all countries in the sample are, ultimately, EU members, and the EU has set ambitious RE targets, both at a national and EU level, the insignificant GDP coefficient is not disturbing and has been found in the literature (Jenner et al., 2013). Coincidentally, the statement above finds support in the results obtained for the EU member binary variable, which shows a positive effect in fostering RE capacity, despite not being significant in two of the five specifications. The political tendency of a country is not statistically significant in RE deployment. This result coincides with the findings in Hitaj et al. (2014) for Germany, but opposes to those of Fabrizio (2012) for the United States, who found a significant effect of political tendency on RE deployment. This makes clear that the ideological difference regarding environmental issues is not as strong in the EU, as it is across the US.

The estimates on electricity consumption are significant and positive. Our model estimates a 0.032 GW increase in capacity per each additional TWh of electricity consumed. Indeed, electricity consumption could have either a positive or negative effect, depending on which type of source was used to meet the higher demand, resulting from higher consumption. The positive results indicate that RE sources are used more extensively to supply this increase, in the margin. Population density was used to proxy the RE potential of a country. Its result does not coincide with the initial expectation. However, since this variable combines both area and population, it may be case that a higher density level can be due to either higher population or lower land area. In any case, the result is not significant and close to zero.[5] Emissions of carbon dioxide have no significant effect on RE deployment. This result follows the literature in both the sign and significance (Kilinc-Ata, 2016) and could be explained by a conflict between social awareness and pressure towards less pollutant alternatives and disengagement regarding environmental causes. Finally, a higher share of fossil fuels has a negative effect on RE capacity, with similar results found in Nicolini and Tavoni (2017) and Jenner et al. (2013). An additional TWh of electricity generated from fossil sources decreases renewable capacity by 0.026 GW. Two possible explanations arise. The first highlights the effect of lobbying in

[5]The variable ***Area*** was used as an alternative proxy. Its results were similar.

maintaining fossil fuel sources. The second relates to the fact that fossil sources are a substitute to RE, and as such, more usage of fossil energy does not exhaust the existing RE capacity and does not push for its increase.[6]

The estimates for the policy binary variables suggest that feed-in policies and quota incentives have a positive effect on RE deployment. On the other hand, tenders and investment grants and tax-based incentives do not seem to produce a significant effect on RE capacity. Moreover, the positive effect of feed-in policies extends to the separate specification, while the in the same setting, quota incentives yield no significant effect.

The results concerning feed-in policies are no surprise. Our model estimates an increase of 0.592 GW in total renewable capacity when the scheme is present. Not only are they the most used policy instrument in the EU, but evidence of its effectiveness has been widely reported in the literature. For instance Nicolini and Tavoni (2017) find a decisive effect of feed-in policies in RE deployment. The estimated coefficients regarding quota policies present an interesting dichotomy. When estimated in conjunction with the other types of policies, its effect is positive and significant, even surpassing that of feed-in policies, of 0.623 GW of capacity. When estimated alone, it is found to have no significant effect in RE deployment. These results suggest that there may exist a complementary/substitute effect and highlight the importance of finding coherent and non-competing policy designs to reach the desired outcome (Zhao et al., 2013). Both feed-in and quota policies produce a larger effect when estimated together, which may indicate these policies have some complementary effects.

6.2 Wind capacity

Column (1) of Table 5 presents the results of the estimation where the dependent variable is added capacity from wind power, which includes both onshore and offshore capacity. The coefficients for the policy variables are disappointing. No policy has a significant effect on the deployment of wind power capacity. While the result for tenders and tax incentives (since it is consistent with the main model) and for quotas (due to its higher sensitivity)

[6] An estimation with share of renewable fuels instead of share of fossil fuels yielded a positive and significant effect.

Table 5: Tobit marginal effects - energy specific

Dependent Variable	Capacity Additions (GW)		
	Wind (1)	Solar (2)	Biomass (3)
Feed-in Policy, (0/1)	0.121	0.468***	0.081***
	(0.090)	(0.171)	(0.028)
Quota, (0/1)	0.219	0.114	0.123***
	(0.154)	(0.197)	(0.036)
Tender, (0/1)	-0.084	0.166	-0.073**
	(0.101)	(0.214)	(0.036)
Tax incentive, (0/1)	-0.006	-0.129	0.035
	(0.129)	(0.151)	(0.031)
GDP per capita, ln	0.078	0.060	0.022
	(0.210)	(0.259)	(0.045)
Left, %	0.194	-0.016	0.189**
	(0.343)	(0.515)	(0.089)
EU Member, (0/1)	0.135	0.777***	0.041
	(0.117)	(0.280)	(0.034)
Electricity Consumption, TWh	0.014***	0.014***	0.001***
	(0.002)	(0.002)	(0.000)
Population Density, population/km^2	-0.000	0.0003*	-0.000
	(0.000)	(0.000)	(0.000)
CO_2 emissions, tonnes per capita	0.006	0.025	0.001
	(0.017)	(0.024)	(0.004)
Share of Fossil Fuels, (TWh)	-0.011***	-0.011***	-0.001
	(0.002)	(0.002)	(0.000)
Constant	-1.396	-2.496	-0.474
	(2.045)	(2.479)	(0.432)
Countries	28	28	28
Observations	476	476	476
Censored Observations	111	154	147

Standard errors in parentheses. *, **, and *** denote significance at 10%, 5%, and at 1% respectively.

are not a surprise, the insignificance of feed-in policies is surprising. Interestingly, the results of the control variables are similar to those found in the main model.

6.3 Solar capacity

Column (2) of Table 5 presents the results for the estimation where the dependent variable is added capacity from solar power. Unlike in the model analysing total RE capacity, only feed-in policies have a significant effect on the capacity of RE from solar power, increasing it by 0.468 GW. The three remaining policies are not significant for solar power.

The results of the control variables remain largely the same. There is, however, a significant effect of population density, which is small and close to zero, and a positive effect of EU membership. This result indicates an increase of 0.777 GW in solar capacity.

6.4 Biomass capacity

Column (3) of Table 5 presents the results of the estimation where the dependent variable is added capacity from biomass power. This estimation is the one where the policy instruments are most effective. As in the main model, feed-in policies and quota obligations produce a positive and significant effect on biomass capacity. The existence of these schemes translates into an increase of 0.081 GW and 0.123 GW, respectively. However, in the biomass power case, tenders are found to have a negative effect, decreasing capacity by 0.073 GW. This result further reinforces the previously mentioned importance of policy design and the existence of non-competing policies, as tenders are schemes which are commonly combined with other policies.

The control variables' results are similar, with the exceptions being the not significant effect of the share of fossil fuels and the positive and highly significant effect of the political tendency. In the case of biomass power, higher support for left-wing parties translates into higher biomass energy capacity. This result, and its departure from the findings of the main model, may be explained by this energy's characteristics, which rely less on the natural endowment of a country and more on the waste management policy.

6.5 Robustness

In this section, we conduct several robustness tests on our results. We abstain from using a different dependent variable for two reasons. First, as outlined in Section 4, because other capacity metrics do not have the characteristics desired for this analysis. Second, because the alternative variable ***Added Generation*** is not suitable for a Tobit model. Instead, we test the robustness of our results by re-estimating our model with different methods. We re-estimate it using an OLS approach, with both random and fixed effects, and a Probit model (with the appropriate dependent variable modifications). Table 6 presents the results.

Table 6: Robustness

Dependent Variable	Capacity Additions (GW)		Capacity Additions (0/1)
	OLS		Probit
	(1)	(2)	(3)
Feed-in Policy, (0/1)	0.451***	0.329**	0.876***
	(0.142)	(0.148)	(0.281)
Quota, (0/1)	0.299	0.945***	0.633*
	(0.221)	(0.300)	(0.379)
Tender, (0/1)	0.029	0.025	-0.297
	(0.164)	(0.164)	(0.333)
Tax incentive, (0/1)	0.015	0.140	0.358
	(0.156)	(0.173)	(0.267)
GDP per capita, ln	-0.419	-0.242	0.827*
	(0.302)	(0.460)	(0.477)
Left, %	0.268	0.800	-0.607
	(0.542)	(0.593)	(0.854)
EU Member, (0/1)	-0.125	-0.128	0.561*
	(0.179)	(0.196)	(0.317)
Electricity Consumption, TWh	0.031***	0.043***	-0.010
	(0.003)	(0.008)	(0.007)
Population Density, population/km^2	0.000	0.000	-0.001***
	(0.000)	(0.003)	(0.000)
CO_2 emissions, tonnes per capita	0.036	0.041	-0.038
	(0.026)	(0.039)	(0.039)
Share of Fossil Fuels, (TWh)	-0.025***	-0.033***	0.017**
	(0.003)	(0.003)	(0.008)
Constant	3.239	0.693	-7.886*
	(2.906)	(4.478)	(4.464)
Countries	28	28	28
Observations	476	476	476
Error Structure	RE	FE	RE

Standard errors in parentheses. *, **, and *** denote significance at 10%, 5%, and at 1% respectively.

Columns (1) and (2) presents the results of the OLS estimation with random effects and fixed effects, respectively. In the random effects specification, only feed-in policies are significant, having a positive effect which increases capacity. In the fixed effects specification, both feed-in policies and quotas are significant and increase capacity. Column (3) presents the estimations of the Probit model. The existence of both feed-in policies and quotas, increase the likelihood of capacity from RE being increased. These robustness tests reinforce our confidence in our results, namely in the effectiveness of feed-in policies and quotas.

6.6 Limitations

Although our results are consistent and robust, they must be interpreted with care, as there may be limitations to the model and to our empirical methods. First, the variables used to assess the effect of policy schemes may have limitations in evaluating them. While binary variables prove to be useful, they are rudimentary, since they evaluate the effect in added capacity of a simple scenario, whether the policy exists or not. An alternative avenue for future research on the topic of support schemes' effectiveness could be to use other measures of policy, such as the amount of the tariff or premium, in the case of feed-in policies, or the required quota, in the case of quota obligations.

Second, the analysis can suffer from an endogeneity problem, as a simultaneity bias can occur between the existence of the variables and the decision to invest and add RE capacity. Despite that, it does not yet exist an accessible method to address endogeneity, using instrumental variables, in a panel data random effects Tobit model, we attempted an OLS instrumental variable approach. Although the endogeneity hypothesis was supported, our choice was not to analyse and discuss the estimates obtained, since the instruments proved to be faulty and not valid.[7] Nevertheless, as IV estimation techniques are developed and better instruments are uncovered, endogeneity, and its correction, could be a further step in the evaluation of policy effectiveness.

7 Conclusion

In this thesis, we investigated to what extent the instruments used to support RE in the EU contributed to the increased share of these sources in electricity production. In particular, We analysed a panel of all 27 members of the European Union and United Kingdom between 2001 and 2017.

Our findings are twofold. First, we find that not all policies are effective. In fact, tenders and tax incentives and investment grants produced no significant effects on the deployment of total RE. On the other hand, feed-in policies and quotas did have a positive

[7] Tables 8 and 9 in the appendix present the variables used as IVs and the results of the IV estimation, respectively.

effect on total RE deployment. Of these two, feed-in policies proved to be the most effective scheme. Second, by analysing all four policies together and separately, we find better results when they are analysed together.

We also control for policy heterogeneity and analyse three different RE sources separately. For wind power, no policy proved to significantly contribute to its deployment. For solar power, only feed-in policies were found to be an effective scheme. For biomass power, both feed-in policies and quotas were effective, whereas tenders were found to have a deterring effect.

These results allow us to draw important conclusions regarding policy interactions (complementarity/substitutability) and design. That is, when implemented simultaneously, policies must have clear targets (i.e. the specific projects or energy types they are aimed at) and objectives (e.g. reach a 20% share of renewable energy by 2020) and must not compete with each other. In fact, in case two properly designed policies co-exist, they can complement one another and ultimately achieve better results. These findings are relevant for future policy design. They show that no policy has a "one size fits all" and that, although policies not targeting a specific source can be effective, tailored policies produce more effective results.

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Appendices

Table 7: Variables in the analysis

	Variable	Unit	Source
Dependent Variable	Added Capacity	GW	IRENA
Explanatory Variables	Feed-in Policy	Binary	IEA, CEER and Held et al. ((2015))
	Quota	Binary	
	Tender	Binary	
	Tax incentive	Binary	
Control Variables	GDP per capita	natural logarithm, constant 2011$	World Bank
	Left	Percentage	ParlGov
	EU Member	Binary	European Commission
	Population Density	population/km^2	Eurostat
	Electricity Consumption	TWh	Eurostat
	CO_2 emissions	tonnes per capita	European Environment Agency
	Share of Fossil Fuels	TWh	Eurostat

Table 8: Instrumental Variables

Variable	Unit	Source
Unemployment Rate	Percentage	Eurostat
Left-leaning majority in Parliament	Binary	ParlGov
Environmental Tax Revenue	Percentage of GDP	Eurostat
Energy Import Dependency	Percentage	Eurostat
CH_4 emissions	tonnes per capita of CO_2 equivalent	European Environment Agency
N_2O emissions	tonnes per capita of CO_2 equivalent	European Environment Agency

Table 9: IV estimation

Dependent Variable	Capacity Additions (GW)	
	OLS	IV
	(1)	(2)
Feed-in Policy, (0/1)	0.329**	1.479***
	(0.148)	(0.524)
Quota, (0/1)	0.945***	1.984
	(0.300)	(1.892)
Tender, (0/1)	0.025	1.195
	(0.164)	(0.813)
Tax incentive, (0/1)	0.140	2.562**
	(0.173)	(1.127)
GDP per capita, ln	-0.242	-0.231
	(0.460)	(0.842)
Left, %	0.800	0.875
	(0.593)	(0.803)
EU Member, (0/1)	-0.128	-0.717**
	(0.196)	(0.361)
Electricity Consumption, TWh	0.043***	0.049***
	(0.008)	(0.010)
Population Density, population/km^2	0.000	-0.011*
	(0.003)	(0.006)
CO_2 emissions, tonnes per capita	0.041	0.045
	(0.039)	(0.061)
Share of Fossil Fuels, (TWh)	-0.033***	-0.031***
	(0.003)	(0.004)
Constant	0.693	0.481
	(4.478)	(7.983)
Observations	476	476
Number of code	28	28
Error Structure	FE	FE
Test for endogeneity (p-value)		0.002
Test for valid instruments (p-value)		0.015

Standard errors in parentheses. *, **, and *** denote significance at 10%, 5%, and at 1% respectively.